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AUTHOR Richardson, J. Jeffrey
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ABSTRACT

In the training of maintenance and operations technicians, three enhancements to a basic, straightforward, fixed-sequence simulation system can be useful. The primary advantage of the resultant system is that the principal object of simulation is the task to be performed, which includes both the planning knowledge and the equipment actions required in task performance. The first enhancement facilitates the development, refinement, modification, and use of a hierarchical task analysis of the job; the second enables the system to adapt its presentation strategy on an individualized basis; and the third provides a means of integrating the conceptual and procedural knowledge related to the performance of the job being simulated. These enhancements use graphics and images as the representation medium for the simulation. When computer assisted instruction (CAI) simulation is coupled with such graphics display as that available with high resolution color graphics terminals, videodisc images, and/or computer-modified videodisc images, the resultant graphics simulations provide a high degree of both physical and psychological fidelity. This graphics simulation is a powerful tool for equipment-oriented operation and maintenance training. (Author/LMM)

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AN INTEGRATED DESIGN AND DEVELOPMENT SYSTEM FOR GRAPHICS SIMULATION

by

J.Jeffrey Richardson

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AN INTEGRATED DESIGN AND DEVELOPMENT SYSTEM FOR GRAPHICS SIMULATION

J. Jeffrey Richardson
Denver Research Institute/SSRE
University of Denver
Denver, CO 80208

Abstract

This paper presents three enhancements to a basic, straightforward, fixed sequence simulation system. The principal application of the resultant system is in the training of maintenance and operations technicians. The principal object of simulation is the task to be performed. This includes both the planning knowledge and the equipment actions required in performance of the task. The first enhancement facilitates the development, refinement, modification and use of a hierarchical task analysis of the job; the second enables the system to adapt its presentation strategy on an individualized basis; the third provides a means of integrating the conceptual and procedural knowledge related to the performance of the job being simulated.

Introduction

The basic contribution to the field of maintenance and operations simulation by the system described below is the recognition that the principal object of simulation is the task to be performed. This includes both the planning knowledge and the equipment actions required in performance of the task. Prior maintenance and operations simulations have focused solely on simulating the equipment upon which

the task is performed. The design elaborated below is a novel and unique departure from previous approaches to maintenance and operations simulation.

A secondary contribution is the use of graphics and images as the medium of representation for the simulation. When CAI simulation is coupled with graphics displays, the resultant graphics simulations provide a high degree of both physical and psychological fidelity. Thus, graphics simulation is a powerful tool for equipment-oriented operation and maintenance training. The graphics capabilities embodied in high resolution color graphics terminals, video disc images, and/or computer modified video disc images provide for realistic equipment representation and manipulation, as well as representation of the processes and concepts important in task performance.

The graphics simulation system is based on the capability to confront the student with a fixed sequence of decisions and equipment actions. The correct decision/action at any given step in the simulation causes the system to advance to the next step. Decisions are input either as choices from a list of alternative answers (multiple choice format) or as natural language input (constructed response format). Equipment actions are input, as nearly as possible, by graphics simulation of actual equipment actions, utilizing video disc images of the equipment.

Each simulation step begins with the presentation of text and graphics which set the scene for the planning decision or equipment action pending. These scenes often summarize the status of the problem

to this point. When an inappropriate decision alternative or equipment action is chosen by the student, a feedback message is presented, followed by a prompt designed to help the student make the correct choice. The student must then try again. The simulation is completed when the student correctly responds to the last simulation step.

The type of simulation just described is not a "free play" simulation. A free play simulation would permit the student to pursue any sequence of decisions and equipment actions irrespective of its correctness. Rather, a "fixed sequence" system is described. Such a system has greater instructional utility than a free play system because (through use of corrective feedback and instructive prompts) the optimal, suggested or recommended approach to a task is developed and reinforced. However, the fixed sequence may include several alternative solution paths for each simulation so that all correct approaches are supported.

The simulation scheme developed thus far places no constraint on how the various steps within a simulation are related; nor upon how steps in different simulations of the same job might be related. These constraints are typically provided by instructional designers through some form of task analysis and instructional planning.

Here is an example of such a design decision. Suppose a series of simulations of the same job is being designed. The level of cueing and prompting might be withdrawn in later simulations. This corresponds to design decisions regarding input response format (multiple choice or constructed response). The multiple choice input presents the student

with a recognition memory task; the constructed response input, a recall memory task. The two differ in that the recognition task provides cueing to the student, while the recall task does not. A fixed sequence simulation scheme can accommodate options regarding input response format, but does not provide design guidance in this area.

Here is a second design example. Again, assume a series of simulations is being developed. Such a series, if well designed, should be coherent. That is, each simulation should present the same set of choices to students when they are faced with the same task or subtask. In other words, the job logic implicit in each simulation should be consistent throughout all simulations. The fixed sequence simulation system described so far can certainly accommodate such consistency; but again, the system offers the designer no assistance in constructing coherent simulations.

A significant portion of instructional materials development effort is expended making such design decisions. Two enhancements to the basic system thus far described provide design assistance to the simulation developer. One helps in the development and use of a task analysis of the job in providing coherent sequences of simulations; the other uses this coherence as a means of modeling student performance, which is in turn used to individualize and adapt simulation presentation to each student's profile of expertise.

Instructional Development Assistance

Task Analysis Development. The development of a quality task analysis can be assisted by an on-line interactive exchange of information between each simulation sequence as it is being developed and a global hierarchy of decisions/actions. This requires that a global hierarchy of decisions/actions be represented on-line. It also requires that each simulation's sequence of steps be represented on-line.

The global hierarchy is a means of representing the alternatives available to the problem solver at each step of the way toward a solution. The correct alternative is determined by the sequence of steps which make up the simulation itself. The simulation provides the sequence of steps; the global hierarchy, the alternatives at each step.

Neither the global hierarchy nor the simulations provide a representation of the rules or conditions under which a given step must be chosen. Indeed, the simulations are developed to illustrate these rules--to make the students face alternatives and apply the rules. The simulation system is primarily a practice medium, not a medium of expository instruction. Students must come to the simulations with a rudimentary understanding of the decision rules of the job. Their understanding then grows through experience and the corrective feedback and prompting provided at each step of a simulation.

In the hierarchy, a task is represented as a node; major subtasks as subnodes. The process is repeated. Each node in the hierarchy is successively refined into subnodes until a level of

decomposition is reached where (for the given task under analysis and the given competencies of the learners) no further decomposition is needed. For maintenance simulation, the terminal nodes in the hierarchy are equipment manipulations. The upper part of the tree represents the range of planning alternatives that go into selecting various equipment manipulations at the lower part of the tree.

The exchange of information between a simulation under development and the global hierarchy would proceed as follows. The designer is at a given step in a simulation. The global hierarchy automatically provides a list of steps which have immediately followed that step in prior simulations. If one of the steps on the list provided is appropriate for the simulation under development, it is selected as the next step and accordingly incorporated into the on-line representation of the developing simulation. If the list does not provide an appropriate alternative, the designer adds a step to the simulation under development. This causes, as a side effect, the new step to be incorporated into the on-line representation of the global hierarchy. If adding to the global hierarchy causes any contradiction or other difficulty for the already developed simulations, the system interrupts the development process and informs the developer of the trouble. The developer then makes appropriate modifications to the global hierarchy and prior simulations affected by the change.

Task Analysis Use. The primary benefit of the above mechanism for task analysis development results directly: the series of simulations automatically has coherence. There is consistency in the

size of the simulation steps within a given simulation and consistency in the steps used across a series of simulations.

Another design area facilitated by this enhancement is a means of giving students meaningful multiple choice alternatives to choose from at decision steps in the simulation. For any node in the hierarchy, the set of immediate subordinate nodes serves as the list of multiple choice items for that node. Design efficiency also results because a given multiple choice menu, applicable to possibly dozens of simulation steps, need never be explicitly entered by the developer. This is done by software at run time. If a menu change must be made during the development process, it is made only once to the master copy (e.g., in the global hierarchy), and not dozens of times. This capability facilitates hierarchy refinement by reducing the effort associated with making changes. Coherence between simulations is again promoted because simmilar steps in different simulations present the same set of menu items.

The use of the global hierarchy has profound instructional implications: it is an organized list of instructional objectives. It serves to familiarize the student with a set of decisions/actions which constitute the job being learned. When familiarity with the global hierarchy and its application is complete, as evidenced by consistently correct responses on instances of each global node, the student will have mastered the job.

While the design aid presented here helps in the development and use of a quality task analysis, the designer must still ensure that a balanced set of simulations is chosen.

Student Modeling

A second major limitation of the basic simulation system is that it provides no structured means of individualization. As used here, individualization means two things. First, it means accommodating changes in student expertise as learning occurs by appropriately varying such things as the level of cueing provided. Second, it means accommodating differences in rate of learning which exist between individuals. It is most desirable to individualize at the level of the smallest unit of analysis. In the present case, this corresponds to the level of the global node (i.e., each discrete decision/action step within the overall task hierarchy for the job).

Individualization has two requirements. First, a source of variation in presentation format is needed--one cannot individualize if there is nothing to change in the instruction provided. Second, given such variation, a means of choosing the appropriate presentation level for a given global node for a given student is needed. Each of these considerations is discussed in turn.

Variation in Presentation Format. The basic system provides the option of presenting a step in either recognition or recall format. Supplying the variation required for individualization is a very simple matter: either a menu is displayed or it is suppressed. In both cases, the correct answer is the same. However, in one case, the student need only recognize the correct answer; whereas, in the other, it must be recalled.

Further variation in presentation is possible. After a student has mastered equipment actions in the recall mode, the equipment action can be presented in summary form (e.g., the action is performed for the student and the results are summarized). Once a student knows how to set up a voltmeter, it is not necessary to practice this skill each time it is encountered. For planning steps, additional variation is supported by permitting the student to skip planning steps interceding between the current location in the simulation and the next equipment action. This "look ahead" strategy is a recognition that as students become familiar with a procedure, planning steps are performed automatically and need not be explicitly required.

Choice of Presentation Format. Given the option of presenting any given step in any of the above modalities, a means of choosing the presentation level for each step for each student is needed. No such means would be possible if simulations were not coherent internally and externally. Student modeling is accomplished through use of the global hierarchy. Experience (encountering the same step in different situations) and expertise (correctly responding to steps at the level at which they are presented) is recorded on a copy of the global hierarchy. When a step is to be presented, the associated node in the hierarchy is referenced, the student's expertise with this node is read, and an appropriate presentation level is chosen.

The sequence of presentation levels for equipment actions is recognition, recall, and summary. The sequence of presentation levels for planning steps is recognition, recall and look ahead.

The student model equates presentation level with expertise. "Recognition" is the least expertise for a node; "summary" or "look ahead," the greatest. A criterion is established for shifting the expertise level up or down. For example, five consecutive correct responses to steps corresponding to a global node might be the criterion for shifting the level of that node from recognition to recall. Similarly, perhaps one incorrect response would cause a node at the recall level to be reset to the recognition level. When all of the nodes have been shifted to their highest level due to consistently correct responses of the student, the job may be considered mastered.

Relationship Between Enhancements. Individualization accomplished through student modeling requires both a global hierarchy and variation in presentation format. The task analysis design aid presented above provides both of these key elements.

The goal of any instructional design effort is instructional effectiveness and efficiency. Tailoring the presentation of instruction to the characteristics of an individual helps promote both of these goals. Instruction in areas in which the student has known expertise may be avoided--promoting efficiency. The resultant concentration of instructional effort on areas known to need instruction results in effectiveness given that a quality task analysis of the job has been performed.

Conceptual Knowledge Hierarchy

This enhancement is presented last because it has no implications for the previous enhancements discussed. The knowledge hierarchy is a means of connecting two aspects of instruction which are often left unreconciled: theory and practice; or, conceptual knowledge and procedural knowledge. All of the explanations one might give of what a job is, how equipment operates, what resources are available to the problem solver, etc., which are not attached to a particular problem but are offered as general information, can be thought of as theoretical explanation. Theoretical material is usually the type of material contained in student workbooks and the type of material the instructor puts up on the blackboard during lecture.

On the other hand, there are, for the steps in any given simulation, explanations about each step which could be offered, often the feedback messages or prompts. A slightly more general explanation might be offered as a help sequence.

At some level of detail, say at the level of detail of the help sequence, the information presented could be used either as problem specific expianation or general theoretical information. The terminal nodes in the knowledge hierarchy contain these dual purpose explanations. The hierarchical structure above these terminal nodes is used to organize them into a corpus of explanations structured around topics in the curriculum.

Each knowledge hierarchy node is accessed in one of two ways: from the root of the hierarchy or from a step in a simulation which con-

tains a pointer to that node. If the node is accessed as a help from a simulation, the student could, if desired, explore other related nodes by moving through the hierarchy. If the node is accessed from the hierarchy itself, it may be possible, in principle, to run the associated simulation steps as examples.

As simulation step help sequences are designed, one first notes whether there is an appropriate point in the hierarchy to reference. If so, a pointer to this reference is incorporated into the step. If not, a help sequence is developed for the step and then integrated into the hierarchy. Similarly, conceptual information is archived into the hierarchy directly. Hence, lecture materials supply potential help sequences; help sequences round out the lecture material. The hierarchy represents both sets of explanations as one. They are useful as lecture support if entered from the outline perspective, and as simulation support if entered via the pointers installed in each simulation step.

Summary

The principal object of the simulation is the task to be performed by the maintenance technician. This includes the planning knowledge and equipment actions required in performance of the task. When CAI simulation is coupled with graphics displays, the resultant graphics simulations provide a high degree of both physical and psychological fidelity. Thus, graphics simulation is a powerful tool for equipment-oriented operation and maintenance training. The graphics capabilities embodied in high resolution color graphics terminals, video

disc images, and/or computer modified video disc images; provide for realistic equipment representation and manipulation, as well as representation of the processes and concepts important in task performance.

The system under development can be viewed as a basic fixed sequence simulation augmented by two levels of enhancement. The first level provides for the development and use of quality task analyses as follows. One comprehensive, integrated set of simulations is to be created. As a simulation is developed, each decision/action point is cross referenced to all similar steps made in other simulations through the mechanism of a global task hierarchy. This interactivity ensures a consistency and coherence of simulation steps, both within and between simulations.

A student model is formed by the use of the global hierarchy to record student experience and expertise across simulations. This model drives a set of selection strategies which promote instructional efficiency and effectiveness by focusing training on those decisions/actions known to need attention.

A knowledge hierarchy helps integrate the conceptual and procedural knowledge related to the job simulated. Terminal nodes in this hierarchy accessed as help frames from simulation steps provide explanation in the context of the problem being solved. These nodes are organized and subsumed as a hierarchy which, when accessed from the top, provides a conceptual explanation of the job, organized around topics.

It is one thing to have an authoring system which permits building sequences of simulation steps. It is quite another thing for such a system to provide design assistance. The enhancements described provide this type of guidance, making the development of quality simulations less critically dependent on the expertise of trained instructional designers.

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